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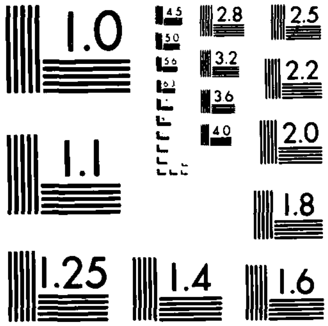

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Orbiting Geophysics Laboratory Experiment

FRANCESCO L. BACCHIALONI

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AEROSPACE INSTRUMENTATION DIVISION   PROJECT 7659

AIR FORCE GEOPHYSICS LABORATORY

HANSCOM AFB, MASSACHUSETTS 01731

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Alva T. Stair, Jr.

DR. ALVA T. STAIR, Jr
Chief Scientist

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Space transportation
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Attitude control system
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document reports the investigation on the potential utility and technical feasibility of a new self-contained support system to be utilized repeatedly for different AFGL experiments in space, using the Space Transportation System (Shuttle) for launch and retrieval. This support system is designed to operate independently of both the STS and ground stations, therefore, stores data rather than transmitting them by telemetry. Angular pointing is the only maneuver planned; no propulsion is designed into this system.

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Preface

The author would like to thank the Air Force Office of Scientific Research and the Southeastern Center for Electrical Engineering Education for providing him with the opportunity to spend a very worthwhile and interesting summer at the Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts. He would like to acknowledge the laboratory, in particular the Sounding Rocket Branch for its hospitality and excellent working conditions. Finally, he would like to thank Mr. Edward F. McKenna for suggesting this area of investigation and for his guidance and collaboration. The author would also like to acknowledge many helpful discussions with Jack Griffin, Russell Steeves, Ray Wilton, William Miller, Roger Jacobs, Kenneth Walker, and several other members of the staff and the help of Dottie Boisvert in typing this report.

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1. INTRODUCTION

With the Space Transportation System (Shuttle) beginning its operational activity, there is the practical opportunity of performing space experiments lasting up to a few days. A normal STS flight may last 7 days, which is a very long time compared with the typical 15-min flight time of a sounding rocket.

Several different techniques may be implemented to utilize the STS for scientific experiments. One technique aiming to avoid space contamination caused by the STS itself is to place the experiments in free space outside of and away from the STS. A small package could be left detached from the STS for a long time, up to a few days, and retrieved by the STS for return to Earth. This report examines in some detail this particular technique.

2. OBJECTIVES

The main objective of this project was to investigate the technical and economic feasibility of building a space platform to be utilized as a support system for AFGL space experiments.

Detailed objectives of this investigation were:

(Received for publication 15 October 1982)

(a) Flight duration,

(b) Data telemetry vs data recording,

(c) Attitude control system,

(d) Power supply.

In this investigation many decisions related to our objectives had to be taken by extrapolation from previous experience resulting from sounding rocket flights and by applying engineering judgment

3. GENERAL CHARACTERISTICS

This platform is to be designed as a free-flying support system for scientific experiments. The STS must supply mechanical support and transportation, deployment in orbit, and retrieval by means of the Remote Manipulator System. The mission is envisioned in this way: when the STS is in orbit, the crew must activate an automatic test of the platform by a radio link switch and watching a Yes-No response before deployment; after this simple test, the STS crew may deploy the platform in orbit and then by radio link activate the experiment mode. The remaining action required of the STS crew is experiment turn-off by radio link, retrieval from orbit, and stowage into the STS payload bay. This minimal dependence on the STS should allow for a wide range of experiments and offer a rapid response to opportunities for flight. Safety considerations should be present at every step of the design. This means that only manned flight-rated component units should be used since testing a non-rated unit is a long, complicated, and expensive procedure.

The probable cost of a reusable support system seems to be lower than that of non-reusable packages even if it is difficult at this time to determine exact figures and the break-even point. Low cost of the platform is a very general design objective that has to be considered at each step by applying engineering judgment based on previous experience from sounding rockets.

4. FLIGHT DURATION

In order to offer a substantial advantage with respect to a sounding rocket, it is clear that our space support system must be capable of operating for the major part of an STS flight, that is approximately seven days. Experiment support and housekeeping must be available for this length of time, offering to the scientists the practical possibility of long experiments. Also, several different experiments can be supported in a single flight.

5. SCIENTIFIC DATA AND SUPPORT DATA REQUIREMENTS

It is considered essential to minimize the STS crew workload and also that of Earth-based telemetry sites. This last point means that all the data resulting from the experiments, plus some housekeeping information, must be recorded on-board. Magnetic tape recording is presently the best method to accomplish this objective. The obvious result of these considerations is that the tape recording system (one recorder or more) is one of the most important subsystems to be installed on the platform. Selection of a flight-approved tape recorder system is probably the first item to be considered when designing our space platform. Direct digital or analog recording choices remains undetermined at this time.

Major considerations are total recording capability and power absorption. It is extremely difficult to establish theoretically the data storage capacity needed for a typical platform mission, but it is possible to reach some reasonable numerical values by extrapolation from the Sounding Rocket Experiments. Engineering judgment based on previous experience should provide a reasonable starting point for the overall design.

A typical 16-min rocket flight generates data which are recorded on one track of tape 9200 ft long. These data include housekeeping data, and amount to approximately $2 \cdot 10^9$ bits of information. By engineering judgment it seems desirable to be able to store at least 10 times the above amount, that is, a total of approximately $2 \cdot 10^{10}$ bits. This would allow the platform to support experiments with fairly fast data collection (2 M bits/sec) for up to 160 min of active measurements. Different recording methods (direct, PCM, HDDR) may be used, but at this point only the total storage capacity is of interest. This value of $2 \cdot 10^{10}$ bits as an estimate for total storage capacity is compatible with existing data recorders; therefore, it can be accepted as a reasonable starting point.

6. SUGGESTED DATA STORAGE SYSTEM

Several different methods could be applied in principle to provide our storage capacity of $2 \cdot 10^{10}$ bits. Conventional RAM chips or bubble memory chips could be used, but their capabilities are presently too limited. Bubble memory chips of 1 Mbit capacity exist, but it is clearly not practical to assemble a memory unit having 20,000 chips. Higher density chips may become available, but not in the near future. Optical recording has the potential for high capacity, but presently it is not available as a developed package. Some companies (for example, Shugart Associates) are presently developing optical storage systems which will involve accurate positioning of laser beams on the recording medium. From a mechanical point of view, these systems seem similar to magnetic tape or disk recorders; therefore, it is reasonable to expect similar limitations, at least for the near future.

This leaves magnetic storage as the logical method to be considered. Disk storage can be quickly ruled out, again, for its too small capacity: a typical 8-in. floppy-disk can store up to 12 Mbits, while 8-in. Winchester drives can store up to 160 Mbits, which is much too little.

This elimination process leaves the magnetic tape recorders as the only practical method for our purposes.

Several companies are presently offering space flight rated tape recorders, and some are also developing new models which are definitely of interest for our Space Platform application. Consideration has been given to the following manufacturers: Odetics, RCA, Lockheed, Honeywell, Ampex, EMI, and Bell and Howell. Information on their recorders is reported here:

Odetics

Model DDS 6000		Model DDS 6000 EC	
Total Storage:	$3.8 \cdot 10^{10}$ bits	Total Storage:	$7.5 \cdot 10^{10}$ bits
Record Rates:	1-32 Mbits/sec	Record Rate:	50 Mbits/sec
Record Speeds:	2.9 to 92 in./sec	Record Speed	75 in./sec
Tape Length:	9200 ft	Tape Length:	9200 ft
Data Tracks:	24	Data Tracks:	38
Record Power:	65-85 W	Record Power:	150 W
Standby Power:	26 W	Standby Power:	30 W
Price:	Approx $1,500,000 plus $300,000 for sealed pressure vessel	Price:	Approx $2,000,000 including sealed pressure vessel

Odetics is presently developing a new unit capable of recording a 1 Mbit/sec for 5 hr on one channel. Power absorption approx 75 W. Price in the $100,000 range. Development time: Approx 2 years.

RCA

Starting development of a new space rated model (ready in 24 to 30 months) having the following characteristics:

Total Storage:	10^{10} bits
Tape Length:	3000 ft
Data Tracks:	12 signal + 4 EDAC
Record Rate:	0.5 - 20 Mbits/sec
Record Power:	45 - 50 W
Price:	Approx $500,000

Odetics

Model MTR 2500

Total Storage:	10^{10} bits
Record Rate:	Up to 20 Mbits/sec
Tape Speed:	Up to 120 in./sec
Data Tracks:	84 (in new design)
Record Power:	25 W (est)
Standby Power:	5 W (est)
Price for 1 unit:	Approx $1,500,000
3 units:	Approx $750,000 each

Price may be lower if ordered with [illegible] specs.

Unit is sealed, tape cannot be removed.

Model Mark VIII (in development)

Total Storage:	$7.5 \cdot 10^{10}$ bits
Record Rate:	Up to 125 M/bits/sec
Tape Speed:	Up to 180 in./sec
Data Tracks:	25
Housekeeping Tracks:	1
Power:	150 W est
Price:	Unknown at this time.
Development Time:	1 y

Honeywell

Model 101

Estimated Total Storage:	$6 \cdot 10^{10}$ bits
Tape Length:	9200 ft
Data Tracks:	28
Power:	480 W

This recorder is not flight-rated, also it requires more power than units made by other manufacturers. Honeywell is presently developing a ruggedized recorder for the Navy. Some information on it will be available in September 1982.

Bell and Howell

Model MARS 1428

Estimated storage density:	16.6 KBit/in.
Data Tracks:	28
Tape Length:	9200 ft
Total Storage:	$5 \cdot 10^{10}$ bits
Record Speeds:	1.875 to 60 in./sec
Record Power:	125 W (including electronics)
Heater Power:	300 W (not always needed)
Price:	Approx $150,000

Ampex

No recorder directly available for space flight. It appears that Ampex is cooperating with Odetics in the field of recorders for space applications.

EMI

No recorder available for space flight.

Again, engineering judgment must be exercised to formulate a reasonable suggestion of a tape recording system. The following characteristics are highly desirable:

(a) Low power absorption,

(b) Variable speed,

(c) Two distinct recorders (to enhance reliability),

(d) Reasonable price.

It seems that the most balanced design at this time consists of a system made up by two Bell and Howell MARS 1428 recorders. Two recorders rather than one allow longer experiments and in the case of one recorder failing, the second one provides storage for part of the experiment. These recorders can be switched on and off so that only one at a time has to be active. One or two tracks on each recorder may be used for error correction, with a corresponding reduction of total storage.

This type of recorder requires power on (in STOP mode, power approx 55 W) for takeoff and landing of the STS, in order to avoid damage to the tape. While the energy consumption is negligible, there is the need of additional circuitry to turn on and off the recorders at the right time.

The required power is rather high but the recorder is proven and relatively inexpensive. The selection of the Bell and Howell MARS 1428 is valid only at this time, since several manufacturers are presently developing recorders worthy of consideration. Therefore, at design time, it will be necessary to reconsider the recorder selection, checking again the various units then available.

7. ATTITUDE CONTROL SYSTEM (ACS)

This platform is designed to be a support system for a vast set of scientific experiments of different duration and pointing requirements. Typical desirable properties are:

(a) Pointing drift in 10 min < 5 sec of arc,

(b) Outgassing as limited as possible,

(c) Number of pointing maneuvers = 5 per orbit,

(d) Repositioning error < 20 min of arc.

Specifications of this order, particularly low drift, require a rather elaborate active ACS. It is clear that in order to have low drift, a good quality inertial reference is required. The "tuned restraint" gyro systems typically can have drift less than 6 min of arc/hr; therefore, this type of inertial reference seems adequate when used in connection with an accurate star tracker. Laser gyros are presently becoming available and should be considered at final design time. Another typical mode of operation is target tracking with pointing error signals delivered by the scientific instruments. This tracking may be required by some experiments and should also be considered when designing the overall ACS. It has to be taken into account that any practical inertial reference required to operate through seven days must be periodically realigned to an absolute reference. A star tracker can be designed to perform this job, and it appears from the technical literature (RCA Technical Communications, for example) that the design of this functional sequence has been successfully implemented. Therefore, no unusual technical difficulty is expected.

The repeated pointing maneuvers and the minimum outgassing requirements dictate the use of reaction wheels for most of the maneuvering. This technique also is well established and offers no technical surprise. Together with the reaction wheel subsystem there is need of a momentum desaturation subsystem, like gas jets or magnetic field torquers. Both momentum desaturation methods involve proven technologies. Gas-jets are quick acting and require reaction gas; magnetic field torquers develop small torques, therefore are slow in action and require electric energy, but no gas. This property is highly desirable, but their small torque may be a serious drawback. The residual tumbing of the platform when released in orbit by the Remote Manipulator System is probably very small (this estimate should be checked with NASA); however, the disturbance torques on the platform probably are rather high, particularly the aerodynamic torques, given the low altitude of the flight.

These considerations probably force selecting a gas-jet system rather than a magnetic field torque system. In order to be able to estimate the gas-jet system activity, a rather detailed analysis of the disturbance torques should be done. This in turn can only be done after the mechanical design is completed.

In conclusion, our ACS must include the following subsystem:

(a) 3-axis stable platform,

(b) Star tracker,

(c) Gas jets,

(d) Reaction wheels.

The entire set of these subsystems is necessary for high-accuracy pointing in a long flight. No additional maneuvering capability is planned at this time: the shuttle will take care of placement in orbit and recovery of the platform.

8. SYSTEM POWER REQUIREMENT

This standard platform is designed to support many different experiments, therefore, it is not possible to predict the exact energy requirements for any possible mission. However, it is possible to estimate the energy need for house-keeping. Here it is in some detail.

ACS	28 W	Continuous
Star Tracker	14 W	Continuous
Reaction Wheels	25 W	Continuous
Tape Recorder	125 W	When Recording
Tape Recorder	0 W	On Standby
On-Board Electronics	25 W	Continuous
Contingency	2 W	Continuous

Total estimated energy for 24 hours, with only 2 hours of recorder operation:

$$(28 + 14 + 25 + 25 + 20) \cdot 24 + 125 \cdot 2 = 2938 \text{ Wh} = \text{Approx } 3 \text{ KWh} .$$

Every hour of additional recording requires 125 Wh more.

Notice that the above figures are rather rough estimates of the power requirement. At design time, a revision of these values is imperative. It is clear that it is desirable to reduce as much as possible the power consumption of the continuously running subsystems, even at the expense of some redesign. This point should be considered carefully at final design time.

The suggested type of tape recorder requires power (55 W per recorder) applied during STS takeoff and landing. It appears possible to apply this power automatically, using accelerometers to close a time switch.

If these accelerometers are sensitive enough to operate during deployment in orbit and retrieval, no harm is done; only a small amount of electrical energy is lost. A small separate power supply (perhaps Ni-Cd batteries) is required to supply power to the Test Controller. The related energy requirement is very small (at most a few Wh) and poses no problem whatsoever. Another separate, very small power supply may be used to energize the system clock, in order to have a stand-alone time source. A small lithium battery probably will suffice for a very long time (thousands of hours).

9. SUGGESTED POWER SYSTEM

Different types of energy sources have been considered. They are listed below:

(a) Lithium Cells - Non rechargeable, high energy per unit mass (300 Wh/kg),

(b) Lead Acid - Rechargeable, medium energy per unit mass (40 Wh/kg),

(c) Nickel-Cadmium - Rechargeable, medium energy per unit mass (40 Wh/kg),

(d) Solar Cells - Virtually unlimited energy, low or moderate power levels. Rather complicated mechanical installation,

(e) Fuel Cells - Possible weight advantage over rechargeable batteries. Expensive and critical in operation,

(f) Silver-Cadmium and Silver-Zinc Cells - Rechargeable, high energy per unit mass (up to 160 Wh/kg). Data from two manufacturers (Yardney and Eagle-Picner) indicate that they are available packaged as batteries, rated for space flight.

Since the total energy needed per each mission is relatively limited, solar cells and fuel cells may be ruled out, considering their mechanical complication and high cost. It is practical to expand the technique used in many sounding rockets, that is, to use rechargeable batteries as power source.

Rechargeable batteries, compared with non-rechargeable ones, offer the advantage of allowing repeated tests of the entire system (platform plus experiment) before launch, without replacement of the batteries themselves. Their use is considered the best choice for our application.

It appears that the weight advantage of the Silver-Zinc cells dictates the use of this type of power source, when compared with the various different possible alternatives. Silver-Zinc cells develop a limited amount of gas (H_2 and O_2) during discharge; therefore, they are vented, but the battery container may be sealed. Venting space has to be provided inside the battery container, and a safety vent is installed on the container itself to protect it in case of abnormal development of gas. A manufacturer (Eagle-Picher) claims that it has succeeded in eliminating the hydrogen accumulation in a sealed batter container by having the hydrogen used up and converted into water by a nickel-hydrogen cell located inside the same sealed container. This technique or some equivalent one is highly desirable, in order to reduce the chance of hydrogen-oxygen explosions.

The energy density of 160 Wh/kg has been used in the following estimates. This value refers only to the cell mass (without container).

Applying the above indicated energy figures it results that 24 hr of operation, including 2 hr of recording, require a cell mass of approximately 19 kg (41 lb) plus an additional 0. 8 kg (1. 75 lb) for each hour of additional recording.

The estimated total mass for a 7-day mission, with a total of 14 hr of recording is approximately 129 kg (2. 85 lb). The mass of the battery sealed container has to be added to this figure.

Notice again that this estimate does not include energy for the experiments.

10. SOME MECHANICAL DETAILS

The mechanical configuration of our platform is extremely important for many obvious reasons. Here are a few:

(a) STS Compatibility - Our platform must be loaded into the STS payload bay, then deployed in orbit and later retrieved from orbit. After landing of the STS, our platform must be removed easily from the STS payload bay. Orbital deployment and retrieval require the existence of a mechanical grapple fixture to be utilized by the Remote Manipulator System of the STS. A support pallet attached to and remaining in the STS payload bay is very likely necessary.

(b) Environmental Control - Pressurization must be supplied to the tape recorders and possibly to the electronic circuits. Temperature control is necessary for the tape recorders and the batteries and possibly also for the electronic circuits. A form of temperature control, active or passive, is needed. It seems at this point that passive temperature control may be realized by enclosing the whole platform into a thermally conducting shell, painted on the outside with an appropriate white/black pattern and properly insulated on the inside. The scientific instruments may be located in a compartment open to space and separate from the support equipment compartment.

(c) Easy Accessibility - It is highly desirable to be able to replace defective units even a short time before take-off. This point does not lead to any preferred configuration, but must be kept in mind at every stage of the final design.

(d) Testing - Attention should be given to laboratory testing of the entire unit. A specially designed mechanical support system should be available for extensive dynamic testing of the entire platform and particularly its ACS, offering three-axis freedom of motion without (or almost without) friction. A good dynamic test program for the platform should simulate all the events that it will see in a single flight; therefore, this test system should be capable of operating for up to seven days without interruption. The platform test mode and its operational mode should be activated, the ACS should work, the recorders activated, and so on.

(e) Launch charge on STS is determined by payload size (in the bay length direction) and/or weight. Minimum length of bay available is 3.5 ft and maximum weight per foot is 1000 lb, for a standard charge. Therefore, it is likely that the space platform would assume the shape of a cylinder or nest of cylinders 3.5 ft in diameter, spanning the bay and weighing approximately 3,500 lb.

11. PROPOSED SEQUENCE OF EVENTS IN A FLIGHT

(a) Platform is tested extensively on ground after installation into STS.

(b) During STS takeoff recorders are automatically energized in STOP mode. Accelerometers determine the exact turn-on and turn-off instants. No crew action is required.

(c) When STS is in orbit, its crew does the following:

1. By radio link closes switch 1 for system test. Platform responds YES or NO.
2. After YES response, crew releases mechanical latch, then by Remote Manipulator deploys platform in orbit.
3. When platform is released and off Remote Manipulator, crew by radio link closes switch 2, starting experiment.

(d) The retrieval from orbit is done as follows:

1. By radio link, STS crew closes switch 3 turning off all systems and discharging residual ACS gas.
2. By Remote Manipulator, crew retrieves platform and secures it on pallet.
3. Pallet mechanical latch is automatically or manually latched.

(e) Power is automatically supplied to recorders in STOP mode, for reentry and landing. No crew action is required.

12. TEST AND EXPERIMENT MODES

It is possible at this point to draw simple block diagrams of the automatic test and experiment modes of operation. Figures 1, 2, and 3 show these block diagrams.

The Test Mode is activated by means of a remotely controlled switch which resets and starts the Test Controller. This mode is available for repeated tests. A diagnostic message for each tested unit will be issued, as a debugging help for ground tests. The same Test Mode will provide the STS operator with a YES or NO message. Eventually, after observing the YES message, the STS operator will deploy the platform in orbit and then initiate the Experiment Mode by remotely closing a separate switch. The Test Mode operation is planned as follows:

(a) Software issues sequentially to port 0 different test codes, in order to activate test mode in each unit to be tested. Appropriate time delays are provided.

(b) Hardware decoder activates test mode in unit corresponding to test code.

(c) Each unit performs test, then issues reponse to corresponding port.

(d) Test Controller reads all unit ports, stores their contents and then issues a diagnostic message for each unit.

(e) After step (d), Test Controller executes another check on stored inputs and issues a YES or NO message.

(f) Test Controller halts, and it is ready to be reset and restarted, unless the Experiment Mode is activated.

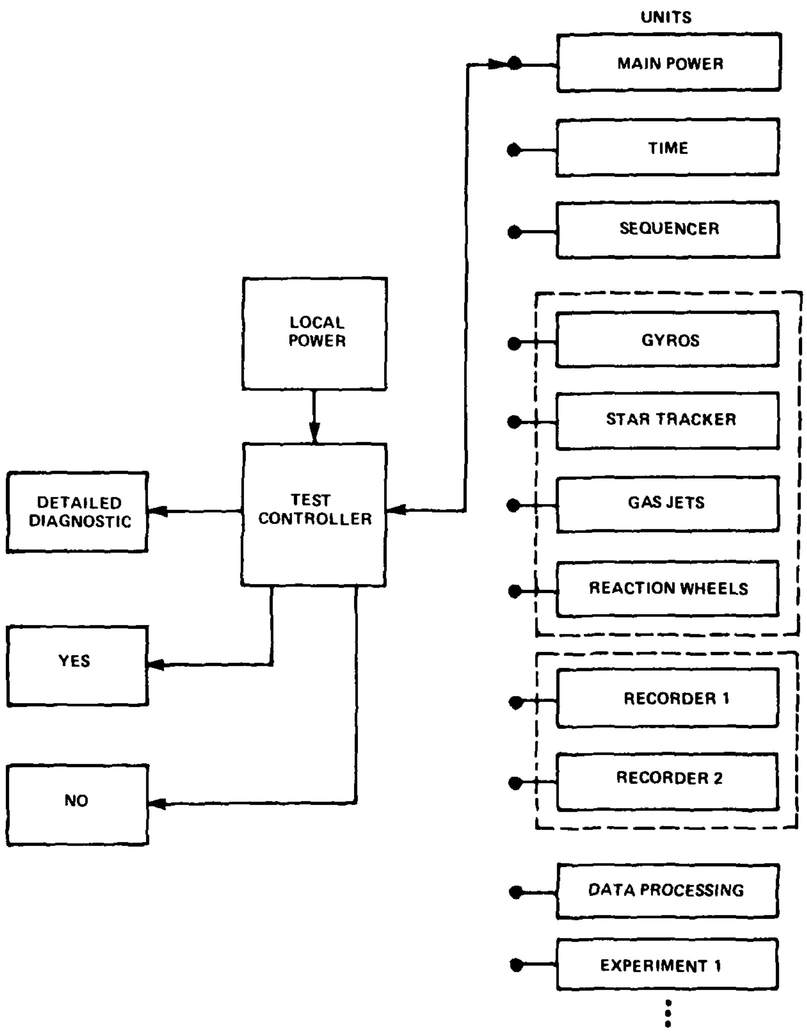

Figure 1. Test Mode Block Diagram

The Experiment Mode is activated by a separate remotely controlled switch. A sequencer turns on the various units and the experiments at the appropriate times. A clock is designed into the system and its output is used to give a reference to the sequencer and to the recorders.

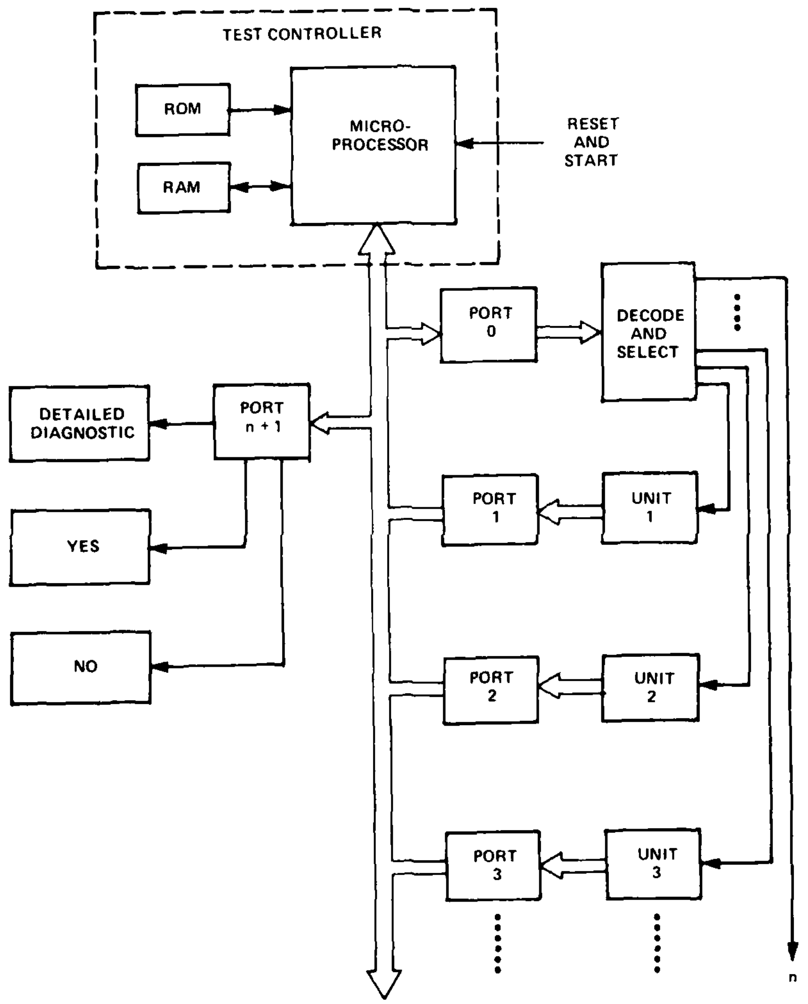

Figure 2. Detailed Handshaking Test Mode

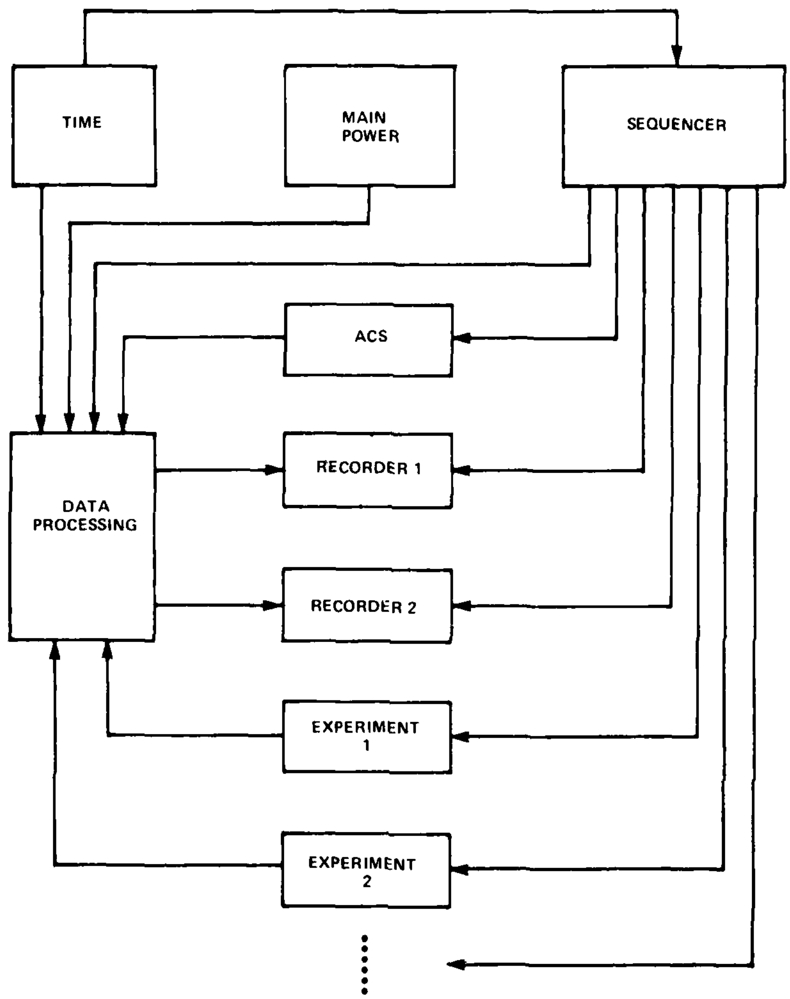

Figure 3. Experiment Mode Block Diagram

13. RECOMMENDATIONS

Increased effort in continuing the development of our Space Platform is in order, since the STS is now entering its routine operations. Economy of operation and possibility of long experiments in space will probably dictate the use of this platform or of a similar device.

The entire development effort should follow the outline here given:

Preliminary Study Concepts
Feasibility Study
Procurement
Preliminary Design
NASA Interface
Shuttle Integration
Design Review
Technical Design Review
Freeze
Fabricate
Integrate and Test
Readiness Review

This paper reports the Preliminary Study concepts and begins to develop the Feasibility Study. The remaining steps should be executed in order to arrive at a working model in a reasonable time, perhaps as soon as 1985.

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